Assimilation of all-sky IR radiances of Himawari-8/AHI and reflectivities of GPM-Core/DPR

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  - Model comparison
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0. Background

- Various satellite data have been assimilated to generate accurate initial states of Numerical Weather Prediction (NWP)
- However, cloud/rain-affected data have been underused
- All-sky IR radiances
  - Mostly assimilated in clear-sky condition, and in overcast conditions at ECMWF
    - All-sky MW radiances have been (will be) assimilated in some operational centers
  - High temporal/spatial information, high sensitivity to clouds
- Space-based precipitation radars
  - Not assimilated in any operational centers
    - JMA is preparing for assimilating RH retrievals
  - Complement ground based radars and space-based passive sensors

1. Preparation for all-sky IR radiance assimilation

- Aim to assimilate IR radiances in general cloud conditions (multilayer, partial, thin and thick,,)
- As the first step, investigate the reproducibility of our model

Himawari-8/AHI : geo-sat after MTSAT2

- Launched in Oct. 7 2014
  - Start the operation in Jul. 7, 2015
  - Himawari-9 to be launched in 2016
- Advanced Himawari Imager (AHI)
  - 1.0/0.5 km for VIS and NIR, 2.0 km for IR and NIR
  - 10 min. for full disk, 2.5 & 0.5 min for Japan regions and target regions (1000x1000km, 1000x500km)
  - 16 band (3 VIS, 3 NIR, 3 WV, 1 CO2)
- Note:
  - Parallel dissemination of AMV and CSR from MTSAT2 will be discontinued in Mar. 24, 2016

    http://www.wmo.int/pages/prog/sat/meetings/documents/IPET-SUP-2_Doc_06-02_Himawari8-JMA-rev.pdf

Himawari-8,9/AHI		
Band	Wavelength [μm]	Spatial Resolution
1	0.43 - 0.48	1km
2	0.50 - 0.52	1km
3	0.63 - 0.66	0.5km
4	0.85 - 0.87	1km
5	1.60 - 1.62	2km
6	2.25 - 2.27	2km
7	**3.74 - 3.96**	**2km**
8	**6.06 - 6.43**	**2km**
9	**6.89 - 7.01**	**2km**
10	**7.26 - 7.43**	**2km**
11	**8.44 - 8.76**	**2km**
12	**9.54 - 9.72**	**2km**
13	**10.3 - 10.6**	**2km**
14	**11.1- 11.3**	**2km**
15	**12.2 - 12.5**	**2km**
16	**13.2 - 13.4**	**2km**

Model and Radiative Transfer Model (RTM)

- Model : JMA-NHM (Non-hydrostatic model)
  - Operational meso-scale model of JMA since 2004 (Saito et al. 2006)
  - Cloud microphysics
    - Explicit three-ice bulk scheme based on Lin et al. (1983)

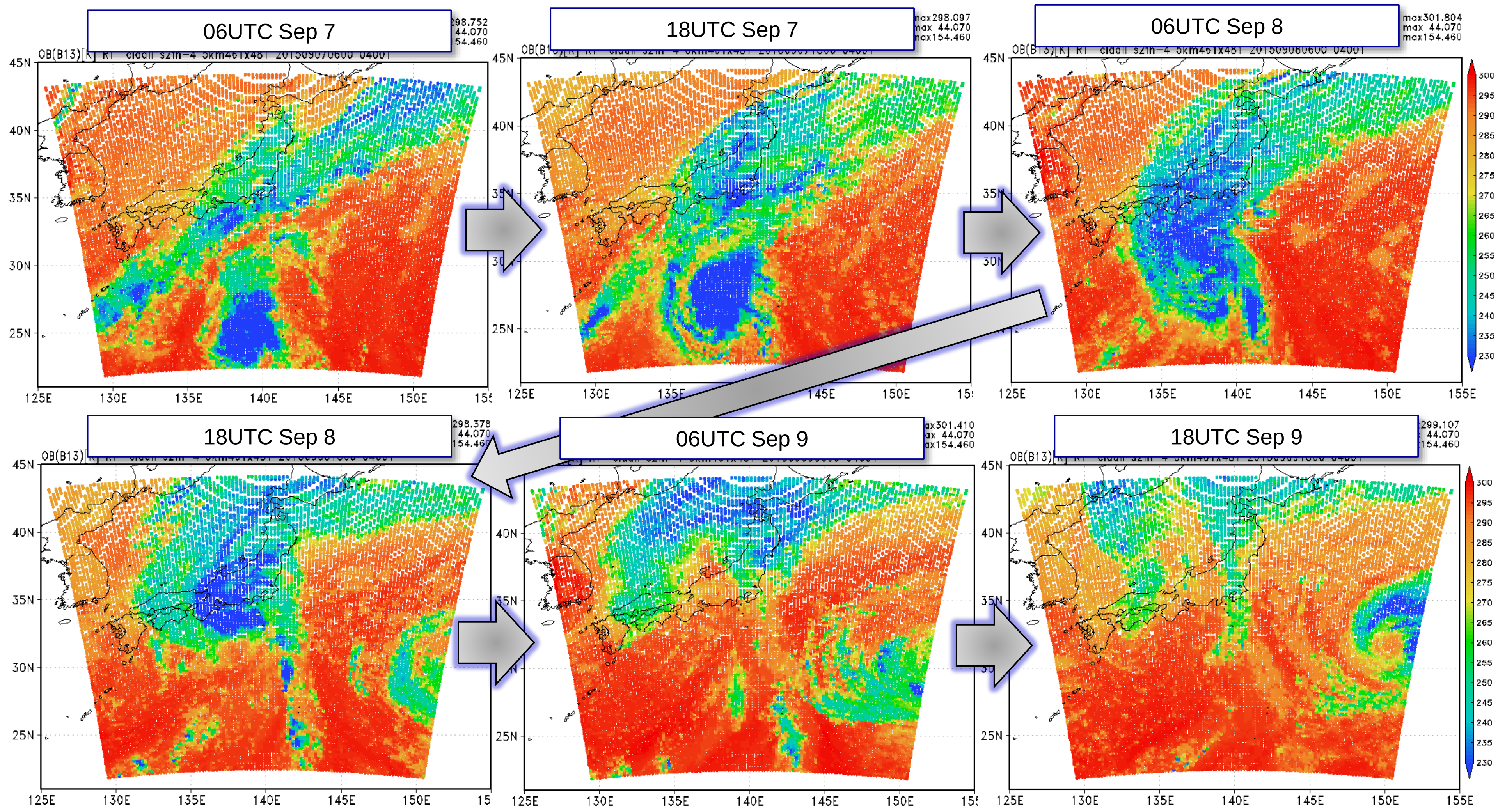
	Cloud water	Cloud ice	Rain	Snow	Graupel
Mix.ratio	Qc	Qi	Qr	Qs	Qg
Num.denstiy		Ni			
DSD	Mono-disperse		Exponential		

- RTM
  - RTTOV v11.3
    - Cloud scattering (Matricaldi 2005): scaling approximation (Fu et al. 1999), cloud fraction by stream method
    - Cloud input: fraction, 5-classified water (convective/stratiform, maritime/continental), ice
  - CRTM v2.2.3 (Thanks to Dr. Paul van Delst)
    - Cloud scattering: ADA method (Liu and Weng 2006)
    - Cloud input: content and effective radius of hydrometeors users specify

Comparison of AHI obs and simulation

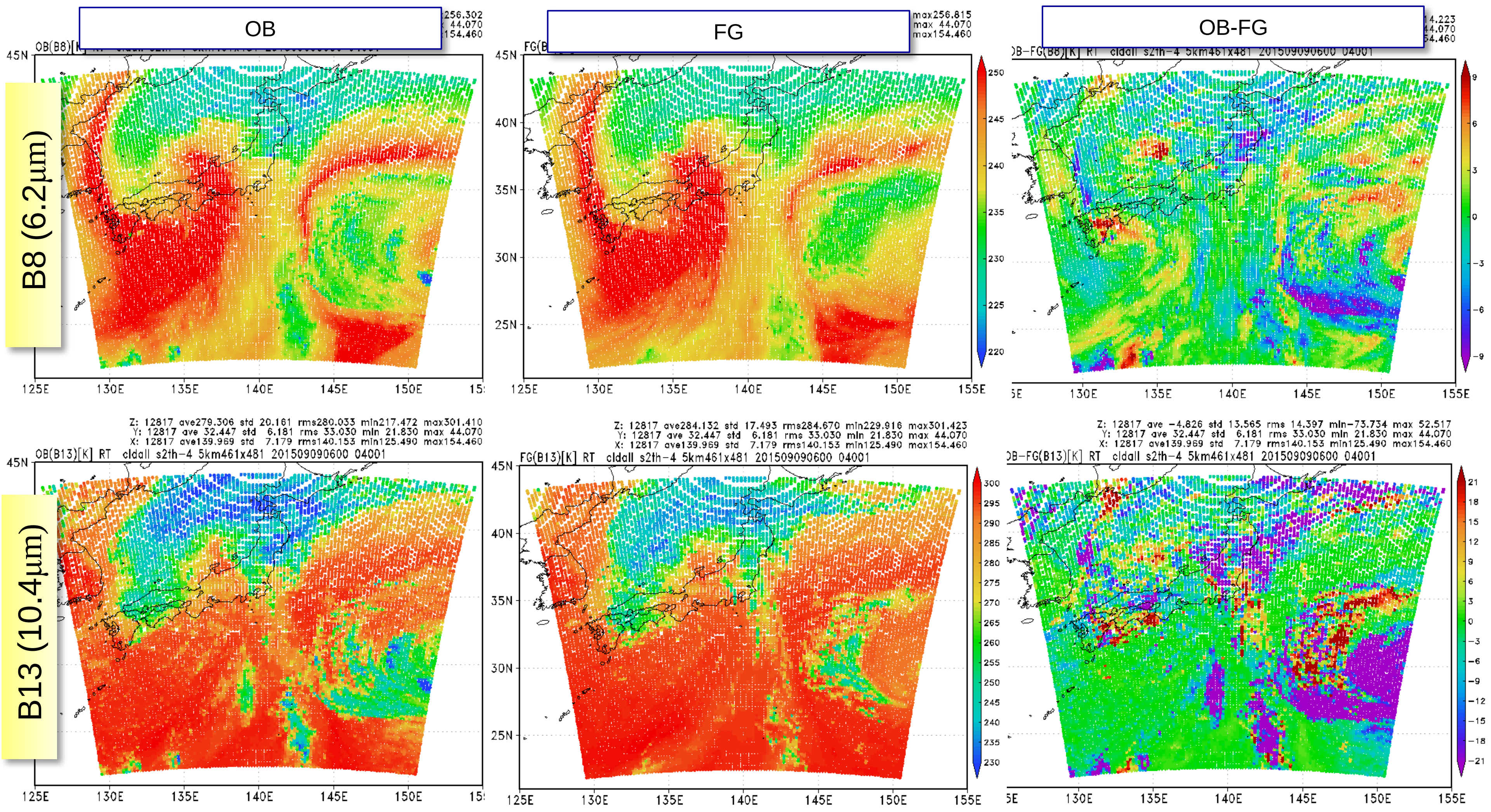
- Model (JMA-NHM)
  - 5km, L50, 461x481 grids, Japan region
  - 6-h forecast, initialized at 00 UTC Sep 7~ 18 UTC Sep 9, 2015, every 6-h
- Obs: AHI IR radiance
  - Super-obbed (2x2 pixels average) and thinned in 20 km box (4 model grids)
  - Removed when standard deviation (SD) in super-ob at band 13 > 2.0 K (inhomogeneity-QC)
    - Intend to remove high inhomogeneous scenes
      → Justify IR super-ob and cloud fraction=1.0 in RTTOV
    - SD is estimated from original pixels inside super-ob
  - No OB-FG screening applied
  - Scatter/PDF plots are made from samples accumulated every 6-h (not every 10-min/2.5-min!) over sea
    - Data number : 116,229
- RTTOV
  - Cloud fraction = 1.0, set “maritime stratus cloud”
- CRTM
  - ODPS algorithm, sea surface emissivity using Nalli coefficients
  - New AHI coefficients (courtesy of Dr. Yong Chen)

OB : Sep 7 ~ 9, 2015



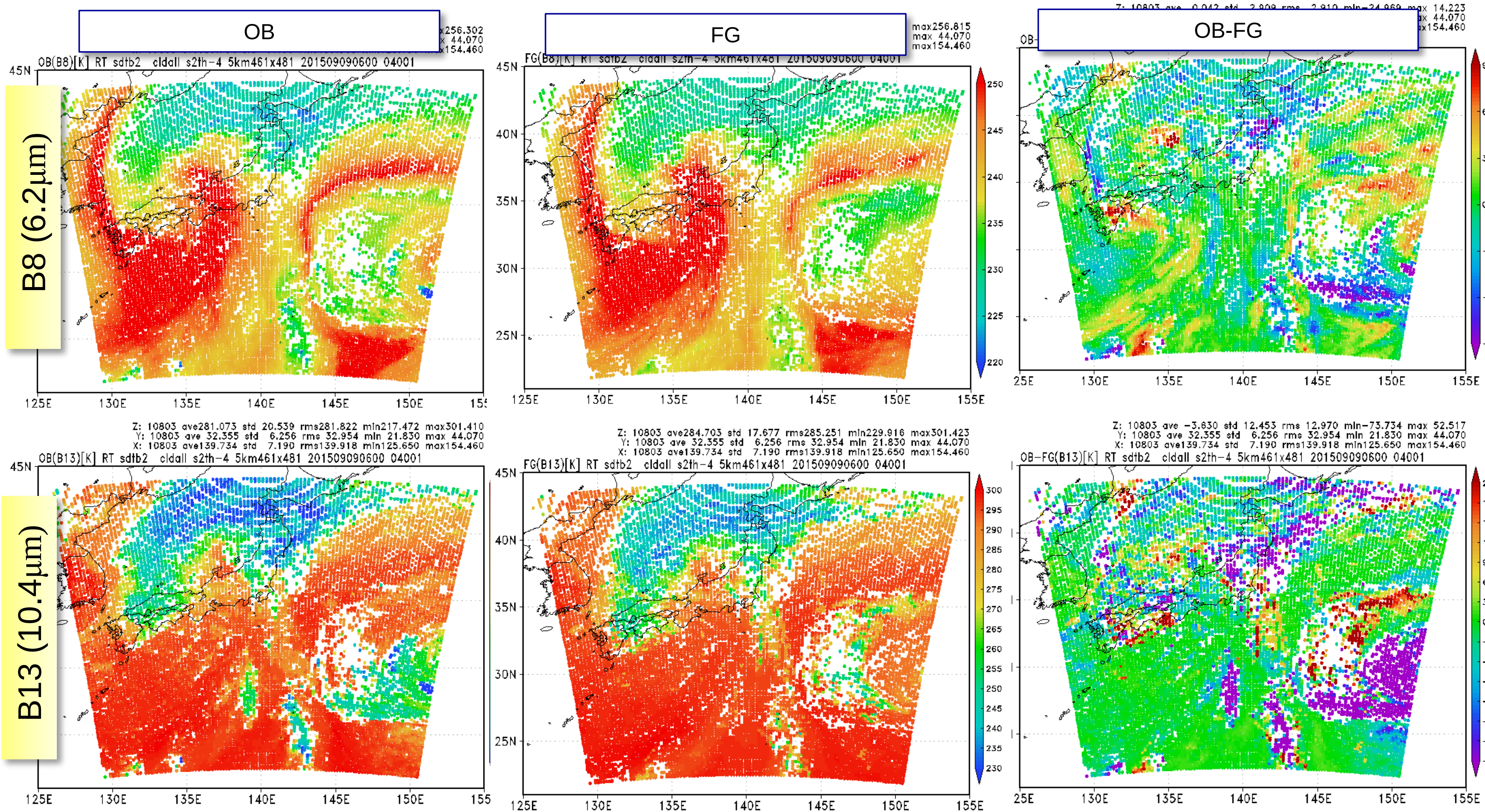
Example of OB, FG, OB-FG with RTTOV

- 06 UTC Sep 9, 2015
- Use RTTOV

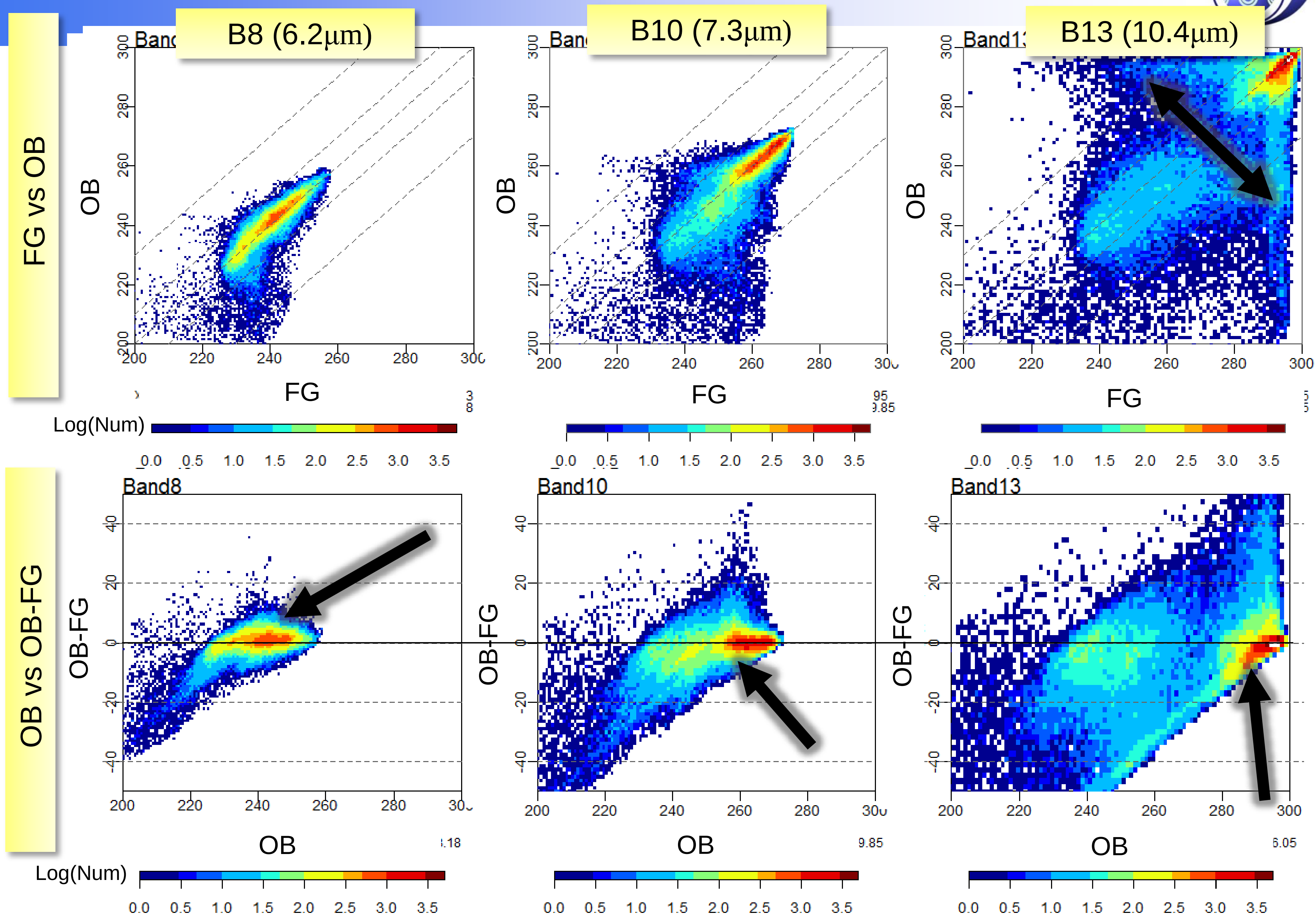


After removing data with SD>2.0K

- Data number : 12,817 → 10,803
- More data should be removed?

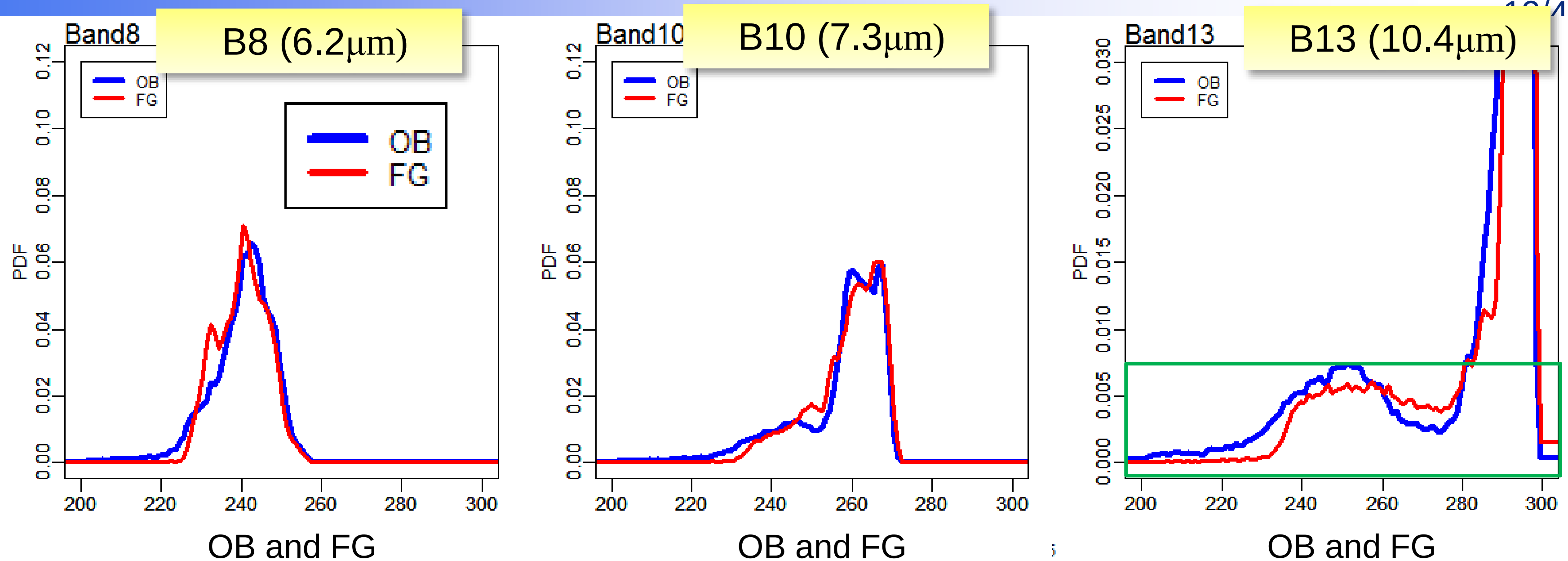


OB vs FG, OB vs OB-FG with RTTOV

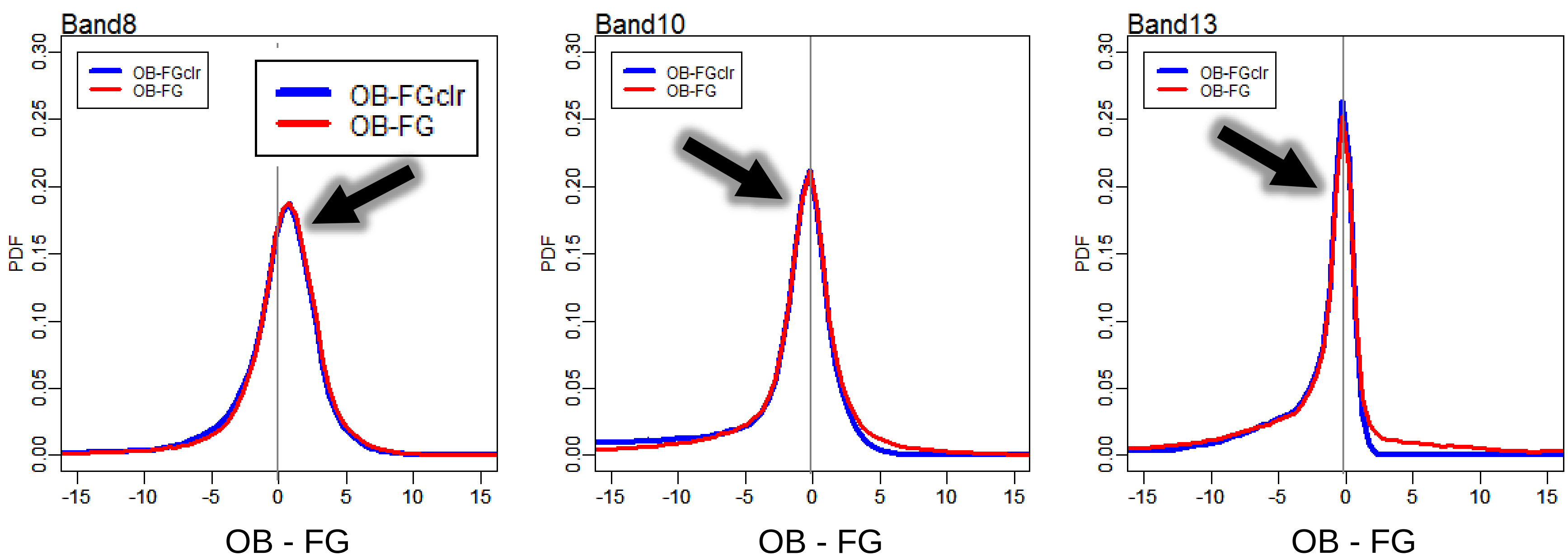


OB, FG, and OB-FG with RTTOV

OB & FG

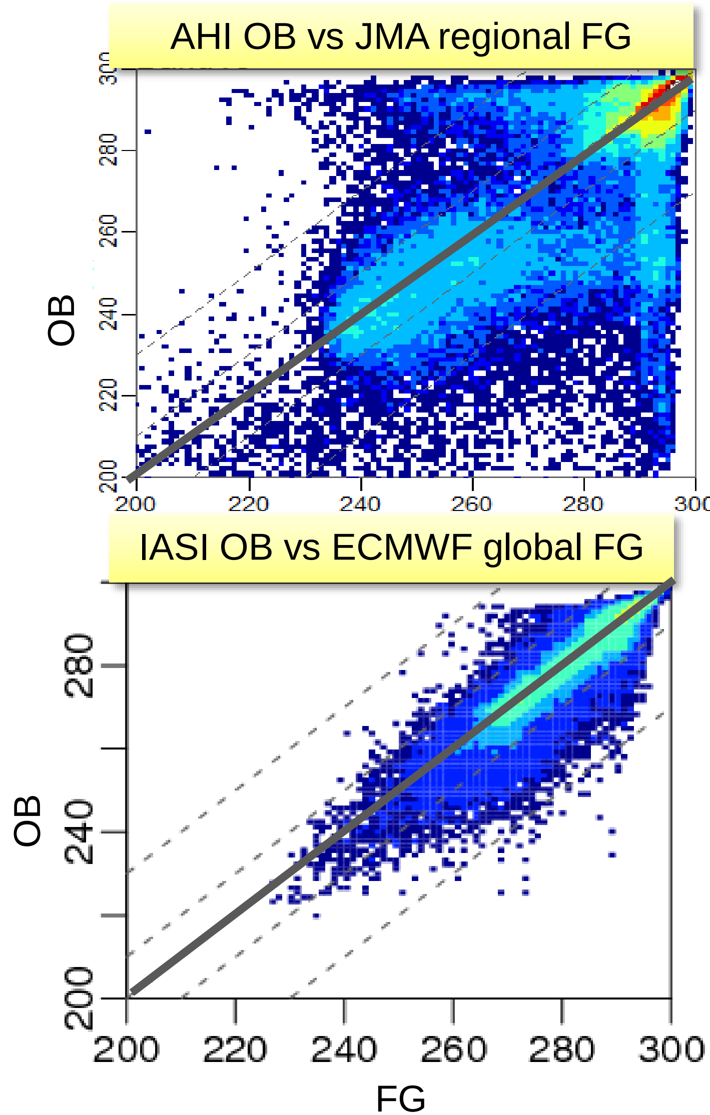


OB-FG

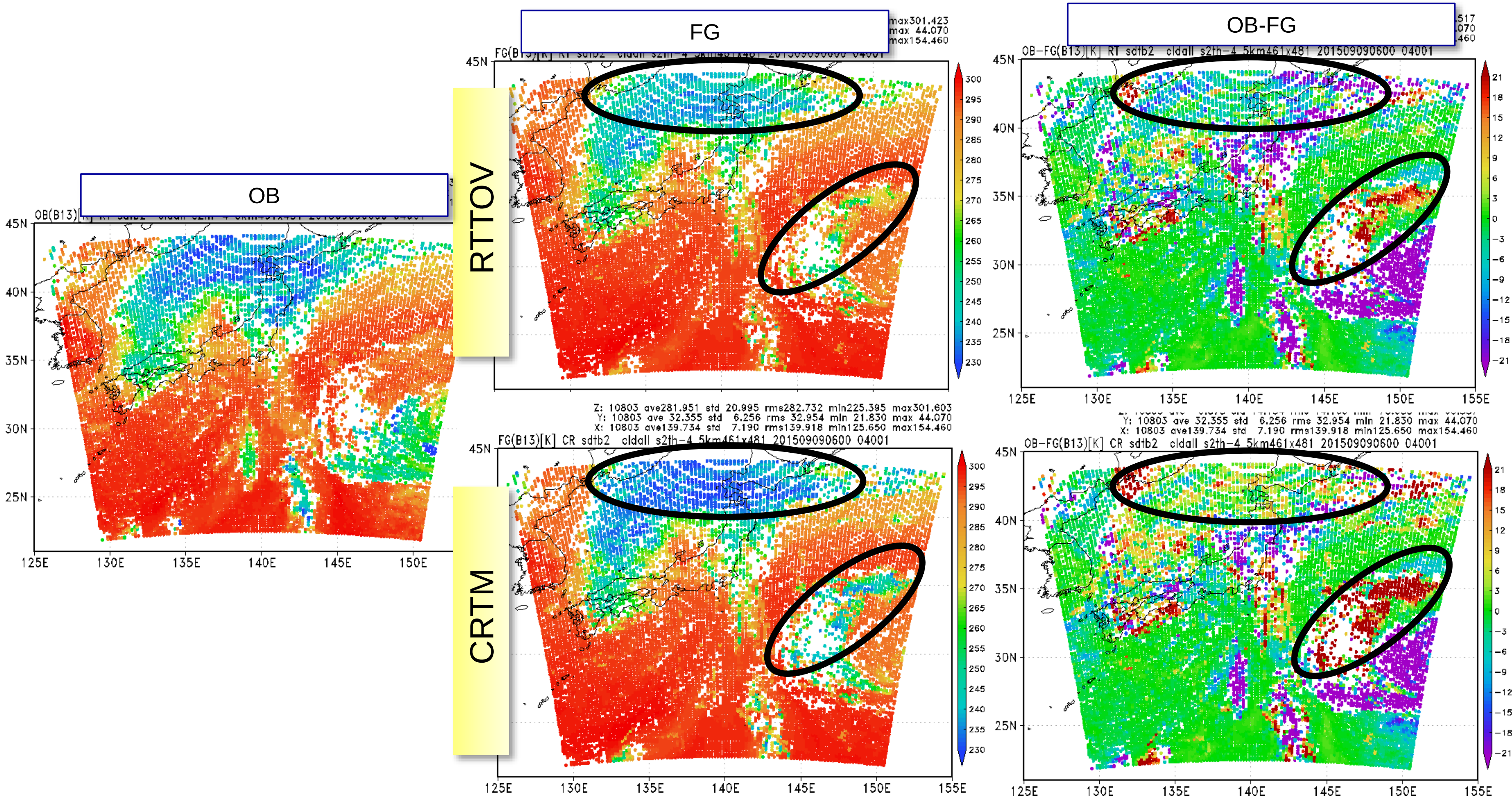


Disagreement between OB and FG

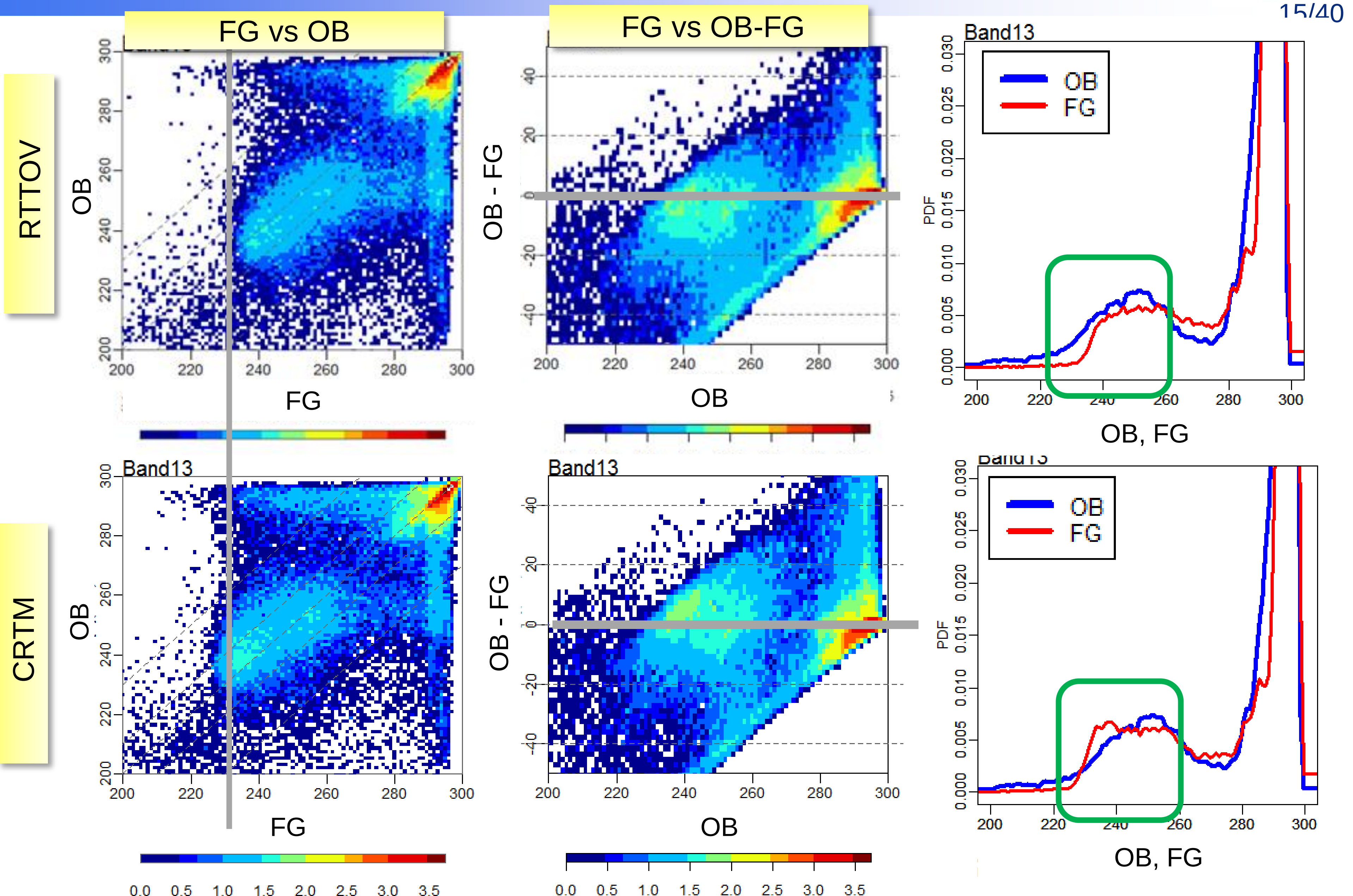
- Low BT at window band is not sufficiently simulated
- Positive OB-FG at humidity band → BT depression due to humidity is overestimated
- From the comparison with global ECMWF-IASI statistics (Okamoto et al. 2014, QJRMS), the regional JMA-AHI statistics shows
  - Larger variability of OB-FG
  - More significant negative OB-FG
- Causes: Deficiency of model, RTM and QC and predictability of high-res system
- What difference does other RTMs make?
  - Help to investigate causes and characterize the disagreement



RTTOV and CRTM (band13:10.4 μm)



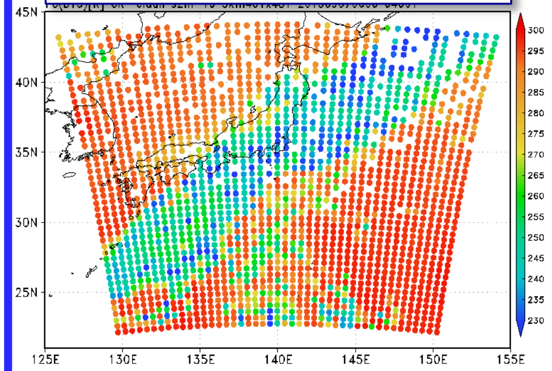
RTTOV and CRTM (band13:10.4 μm)



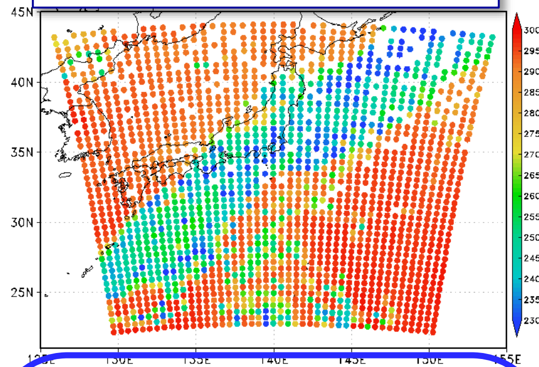
cloud sensitivity of CRTM : FG

MR: mixing ratio,
Re: effective radius

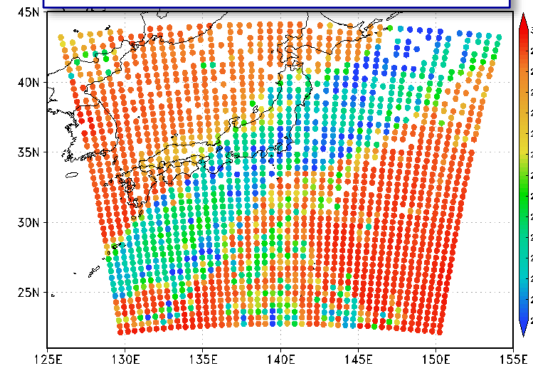
original



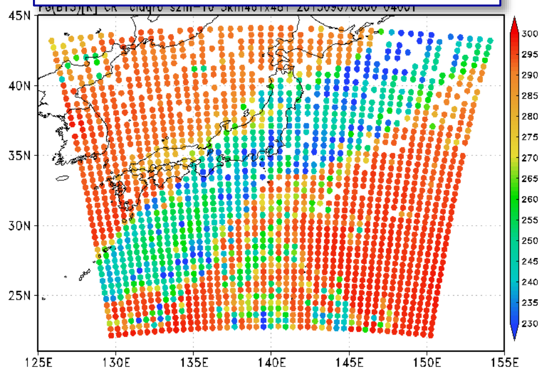
MR of cloud water = 0



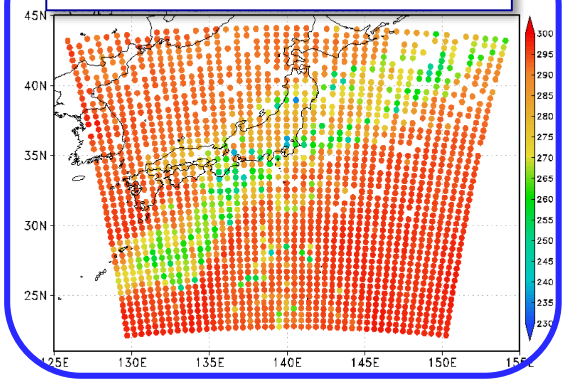
MR of cloud ice = 0



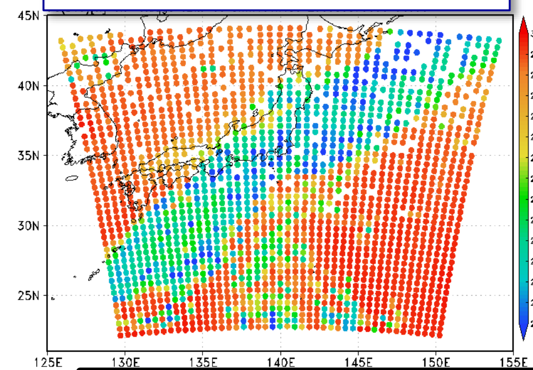
MR of rain = 0



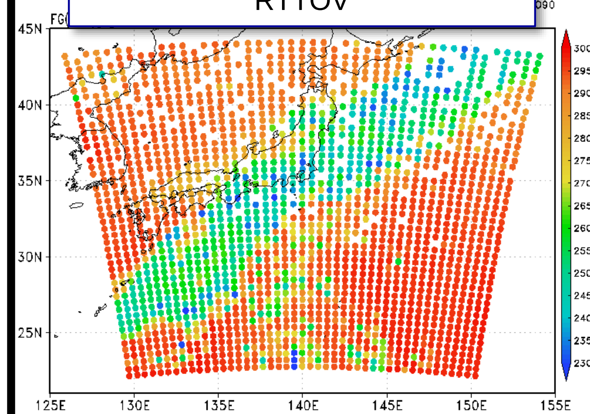
MR of snow = 0



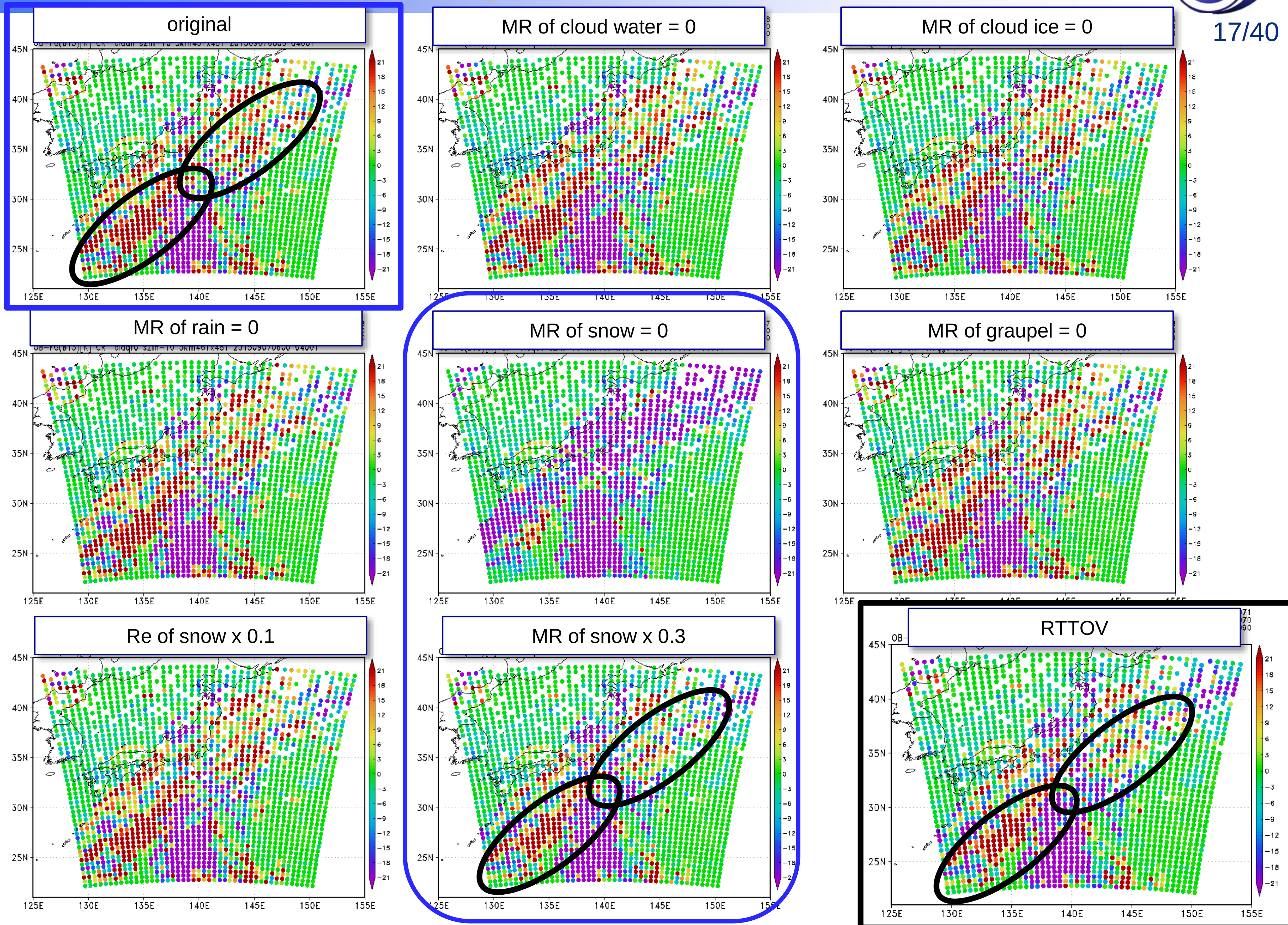
MR of graupel = 0



RTTOV

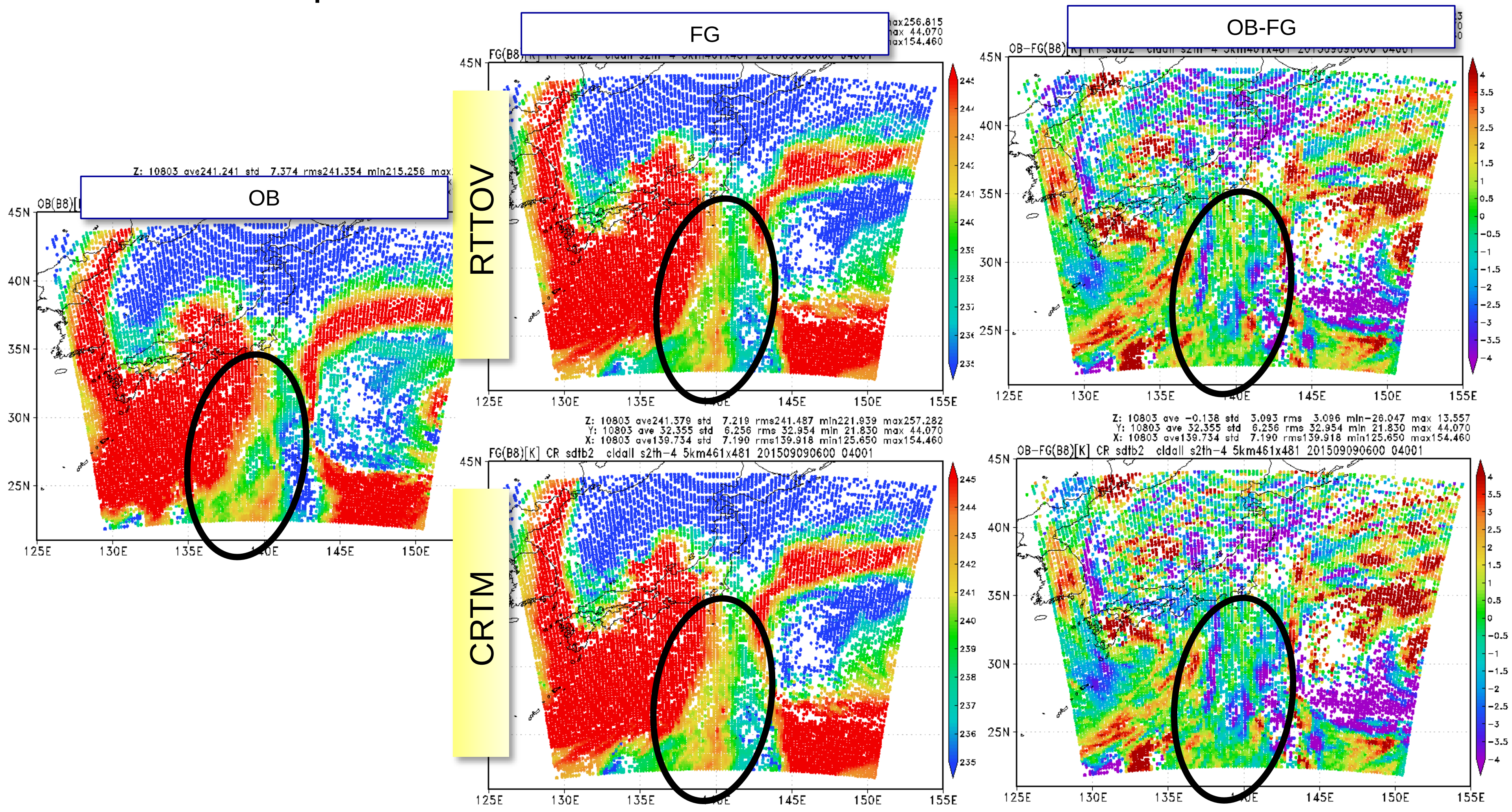


cloud sensitivity of CRTM : OB-FG

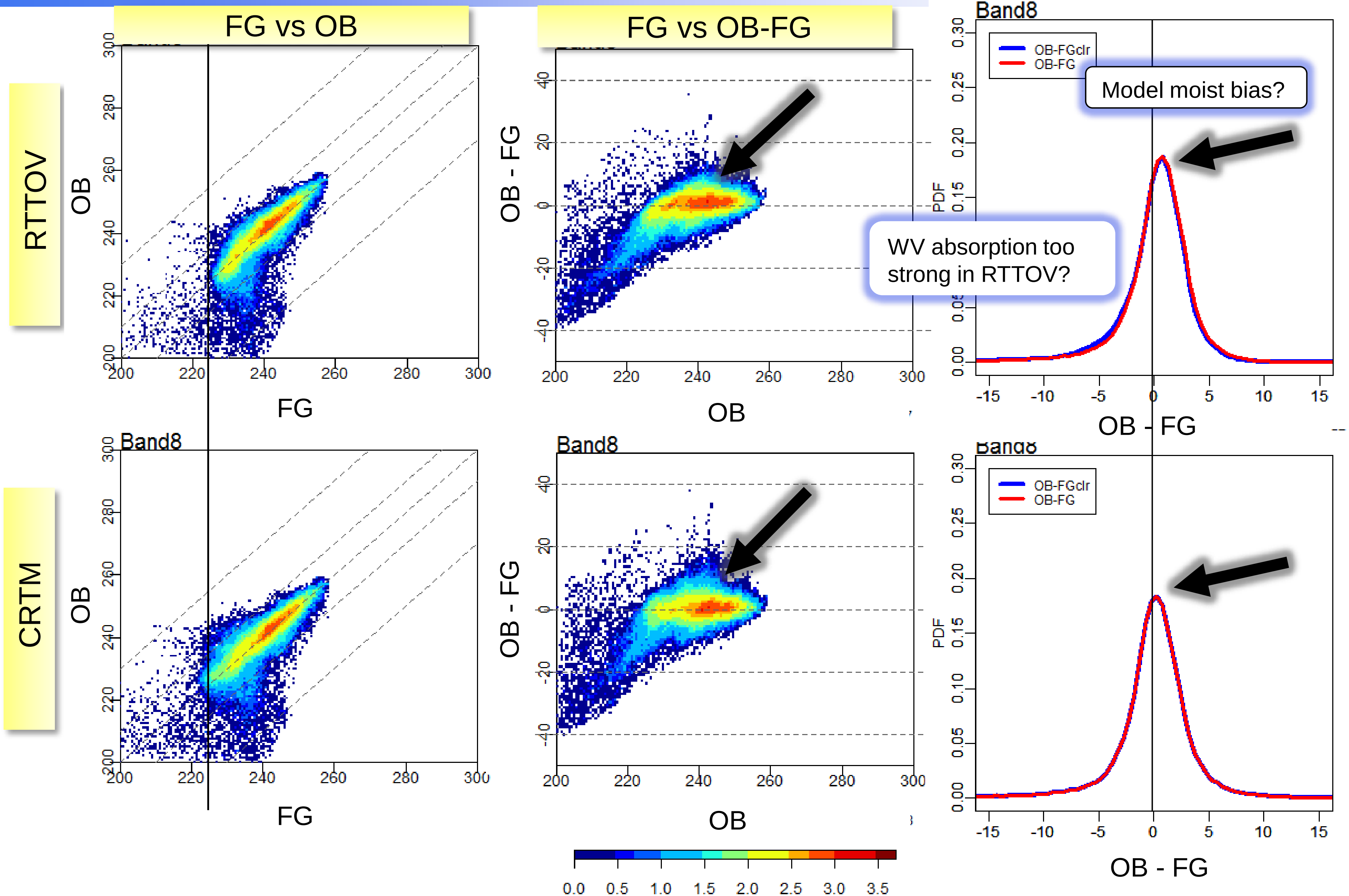


RTTOV and CRTM (band8: 6.2μm)

- CRTM BT is slightly higher in moisture inflow region, probably due to weaker absorption
- → Alleviate positive OB-FG



RTTOV and CRTM (band8: 6.2μm)



RTTOV and CRTM comparison: summary

- CRTM simulates (reasonably) weaker humidity absorption than RTTOV
- CRTM simulates lower BT than RTTOV
  - BT depression is mostly associated with snow (mixing ratio)
  - However, CRTM generates excessively low BT in some clouds
    - → OB-FG variability is larger : SD=13.50K (RTTOV), 14.38K (CRTM)

- Possible explanation of excessively low BT in CRTM
  - CRTM overestimates cloud scattering, and/or
  - JMA-NHM overestimates snow (see DPR CFAD in the 2nd part of my talk)
    - The underestimation of RTTOV scattering may offset model's snow overestimation
  - I would like to know results of other comparison study and verification

Summary and plans of preparation for all-sky IR rad assimilation

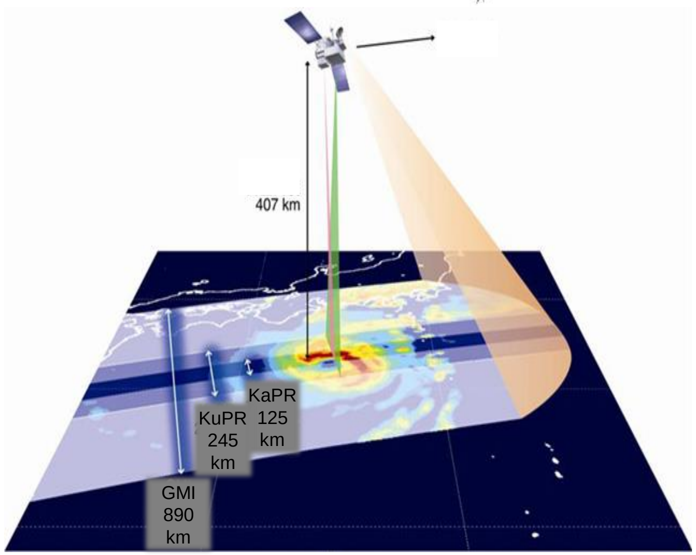
- To assimilate all-sky IR rad of Himawari/AHI, obs is compared with simulation using JMA-NHM with RTTOV & CRTM
- Cloudy radiances are overall reproduced but the large variability and negative bias of OB-FG is significant
- RTTOV/CRTM comparison helps to investigate the cause of and characterizing the disagreement between OB and FG.

- Ongoing
  - Improve a cloud effect parameter to develop cloud-dependent QC and obs error assignment (and bias correction)
    - See my talk in ECMWF-JCSDA cloud/precip-workshop in Dec. 2015
    - Need to remove extreme outliers based on characterized disagreement.
- Plans
  - Continue the comparison study for different weather situations
  - Assimilate all-sky IR using regional and global DA system

2. DPR reflectivity assimilation

GPM-Core/DPR

- GPM (Global Precipitation Mission)-Core satellite
  - GPM is a joint mission between NASA and JAXA
  - Launched on 28 Feb 2014
  - 2 instruments : DPR and GMI (GPM Microwave Imager)
- DPR (Dual-frequency Precipitation Radar)
  - KuPR and KaPR
- Use 2 DPR data in this study
  - KuNS : KuPR normal scan mode
    - 13.6 GHz, Res: 5.2 km (H) & 125 m (V)
    - Swath: 250 km
  - KaHS : KaPR high sensitivity mode
    - 35.55 GHz, Res: 5.2 km (H) & 250 m (V)
    - Swath : 125 km
  - Available on JAXA G-Portal : https://www.gportal.jaxa.jp/gp/top.html



http://www.eorc.jaxa.jp/GPM/index_e.htm

Model and radar simulator

- Model : JMA-NHM
  - Operational meso-scale model of JMA since 2004 (Saito et al. 2006)
  - Cloud microphysics

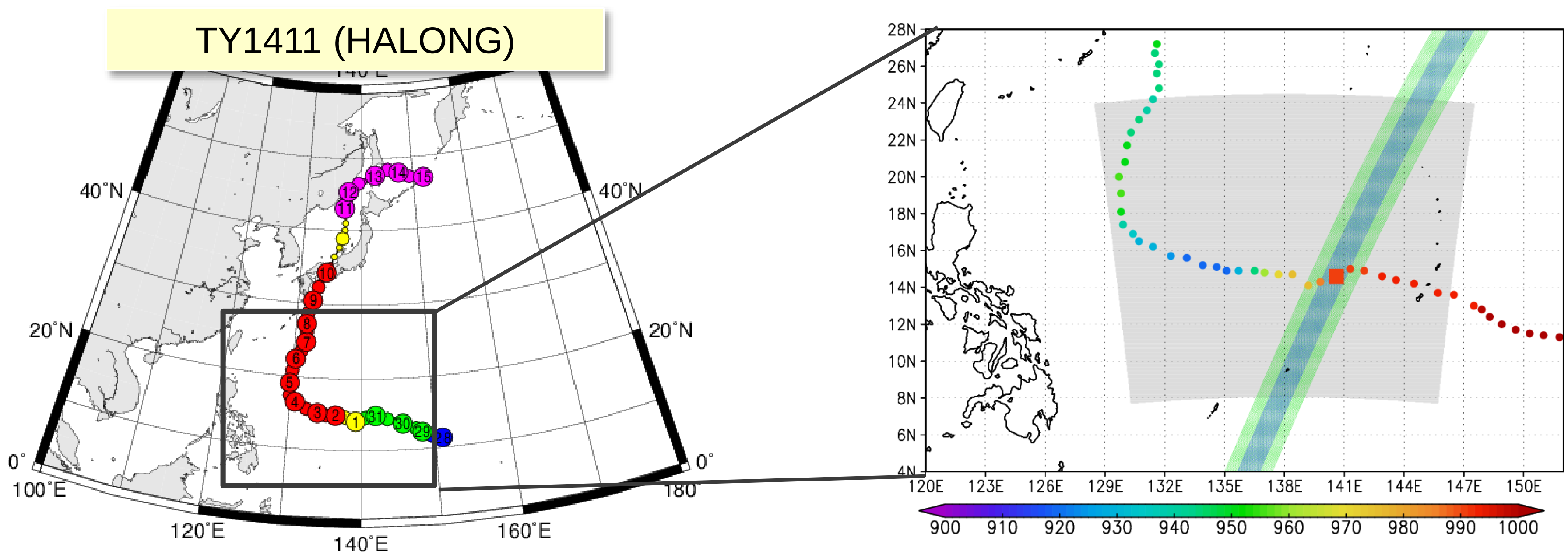
	Cloud water	Cloud ice	Rain	Snow	Graupel
Mix.ratio	Qc	Qi	Qr	Qs	Qg
Num.denstiy		Ni		Ns	Ng
DSD	Mono-disperse		Exponential		

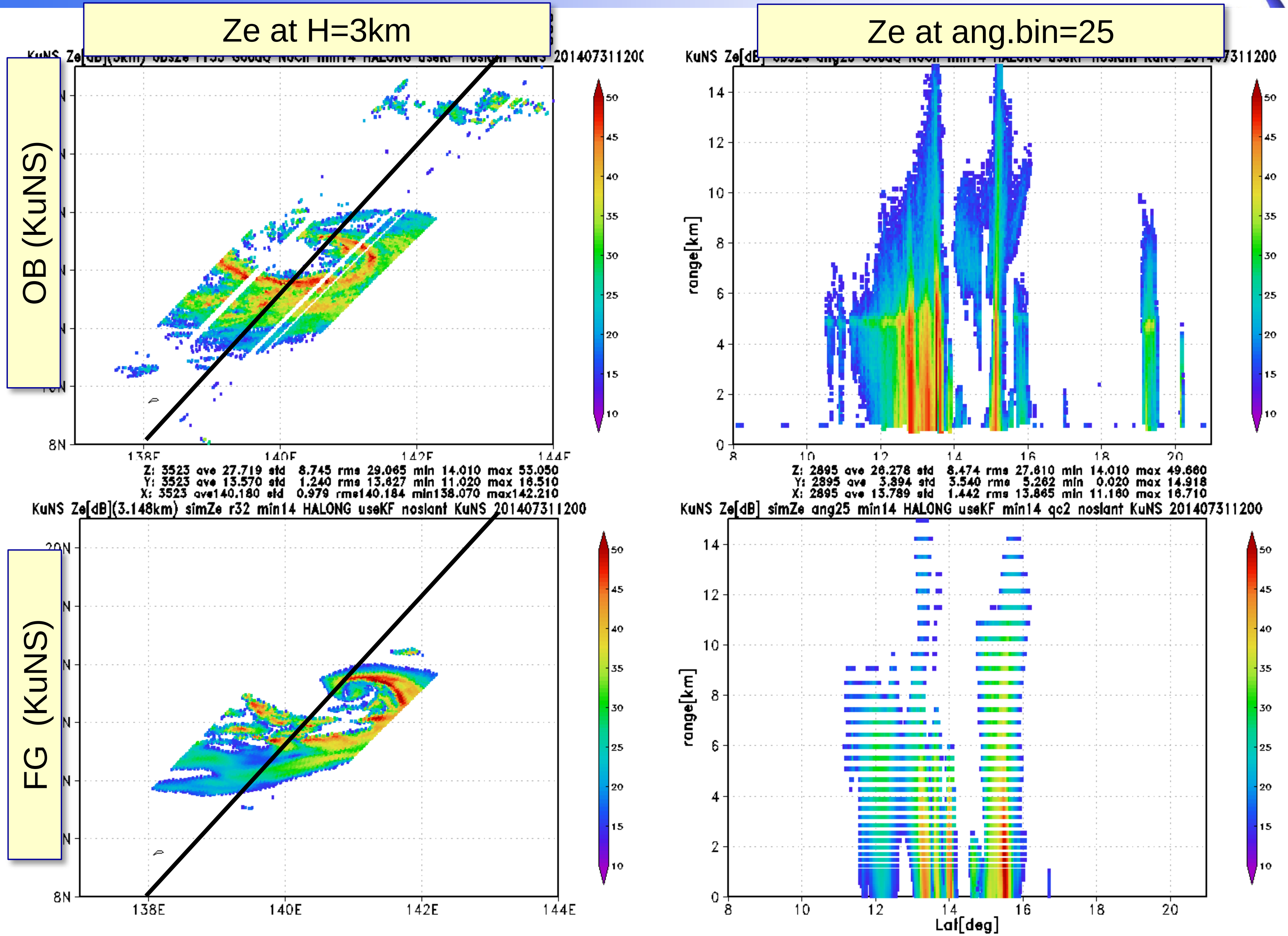
- Simulator : Joint-simulator (Hashino et al. 2013)
  - Developed by JAXA EarthCARE mission and Japanese research community
    - Inherited from Satellite Data Simulator Unit (SDSU; Masunaga et al. 2010) and NASA Goddard SDSU
  - Multi-satellite sensor simulator utilizing cloud microphysical parameters consistent with input cloud-resolving model
  - Calculate reflectivity factor (Ze) based on Masunaga & Kummerow (2005), using optical parameters retrieved from Look-up-table

$$Z = \frac{\lambda^4}{\pi^5 |K|^2} \overline{\sigma}_b \exp\left[-2 \int_0^r \overline{k}_{\mathrm{ext}}(r')\, dr' \right]$$

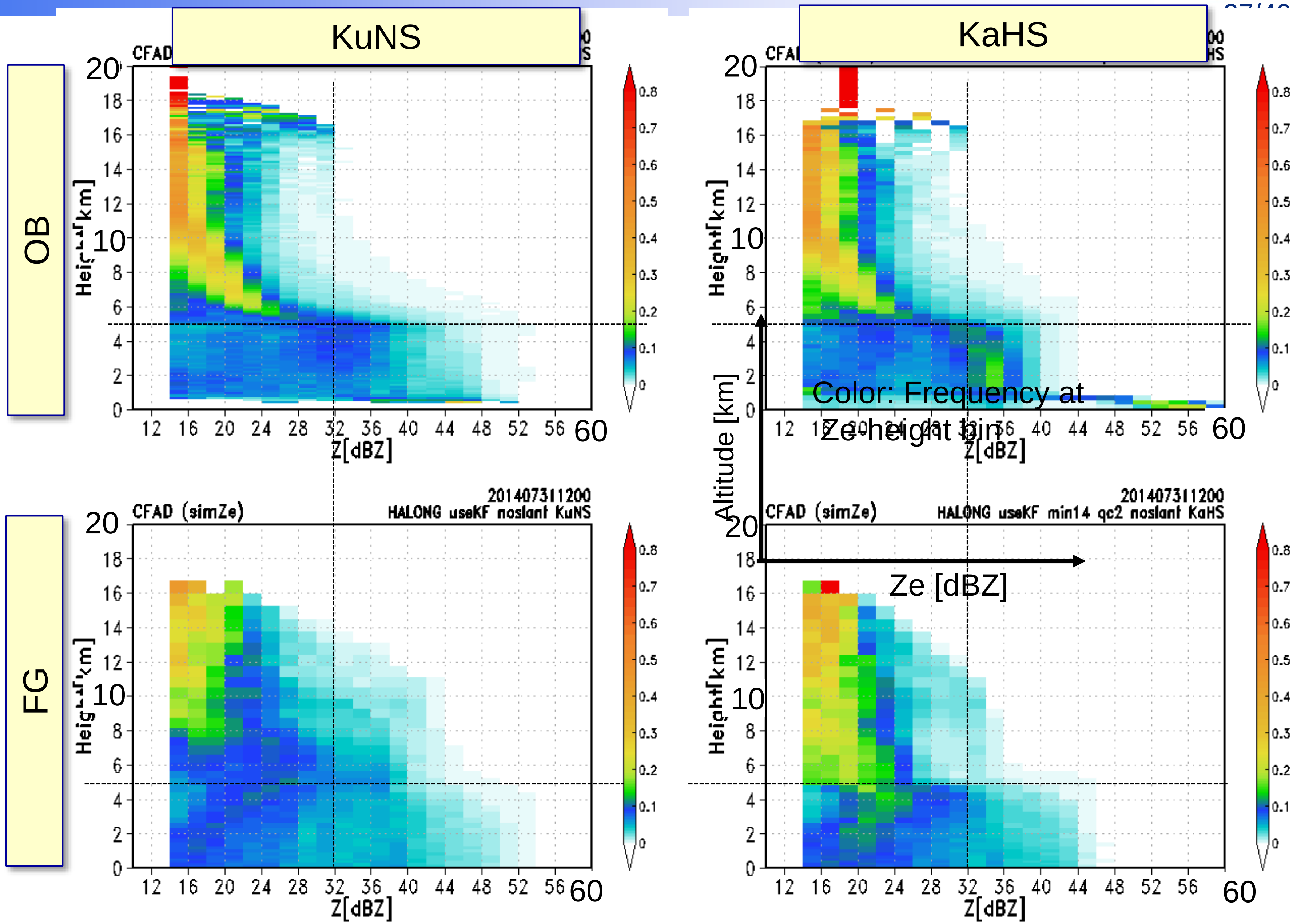
Comparison of DPR obs and JMA-NHM simulation

- Target : Typhoon T1411 (Halong)
- Model : JMA-NHM
  - 12-h forecast from 00 UTC 31 July, 2014
  - 5 km res., 401x401 grids, 50 layers up to 21.8km
- GPM-Core/DPR:
  - 2ADPR (KuNS and KaHS), attenuation-corrected reflectivity factor (Ze)
- Remove data with Ze<14 dBZ and contaminated by ground clutters




Ze at H=3km
Ze at ang.bin=25
OB (KuNS)
FG (KuNS)
Z: 3523 ave 27.719 std 8.745 rms 29.065 min 14.010 max 53.050
Y: 3523 ave 13.570 std 1.240 rms 13.627 min 11.020 max 16.510
X: 3523 ave140.180 std 0.979 rms140.184 min138.070 max142.210
Z: 2895 ave 26.278 std 8.474 rms 27.610 min 14.010 max 49.660
Y: 2895 ave 3.894 std 3.540 rms 5.262 min 0.020 max 14.918
X: 2895 ave 13.789 std 1.442 rms 13.865 min 11.160 max 16.710
KuNS Ze[dB](3.148km) simZe r32 min14 HALONG useKF noslant KuNS 201407311200
KuNS Ze[dB] simZe ang25 min14 HALONG useKF min14 qc2 noslant KuNS 201407311200
range[km]
Lat[deg]
138E
140E
142E
144E
8N
20N

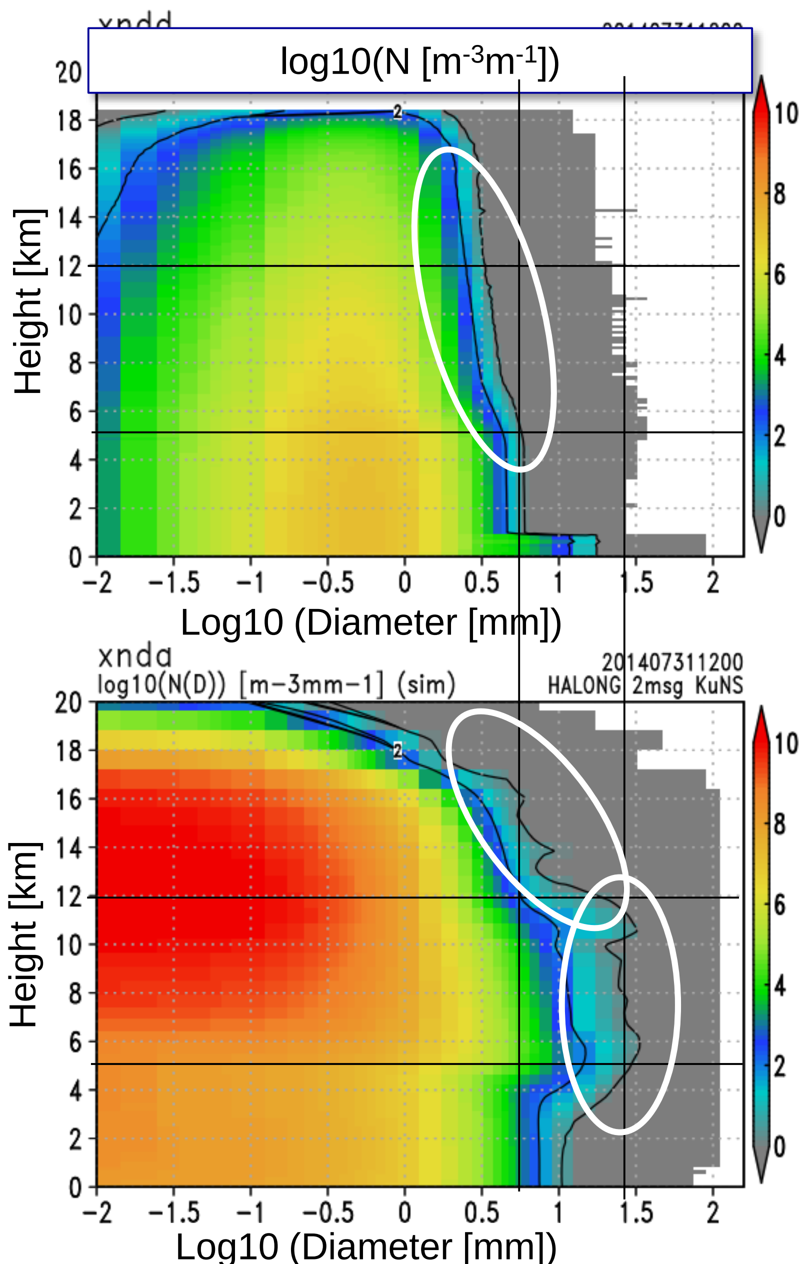
CFAD (Contoured Frequency by Altitude Diagram)



Number density as a function of diameter & height for OB and FG

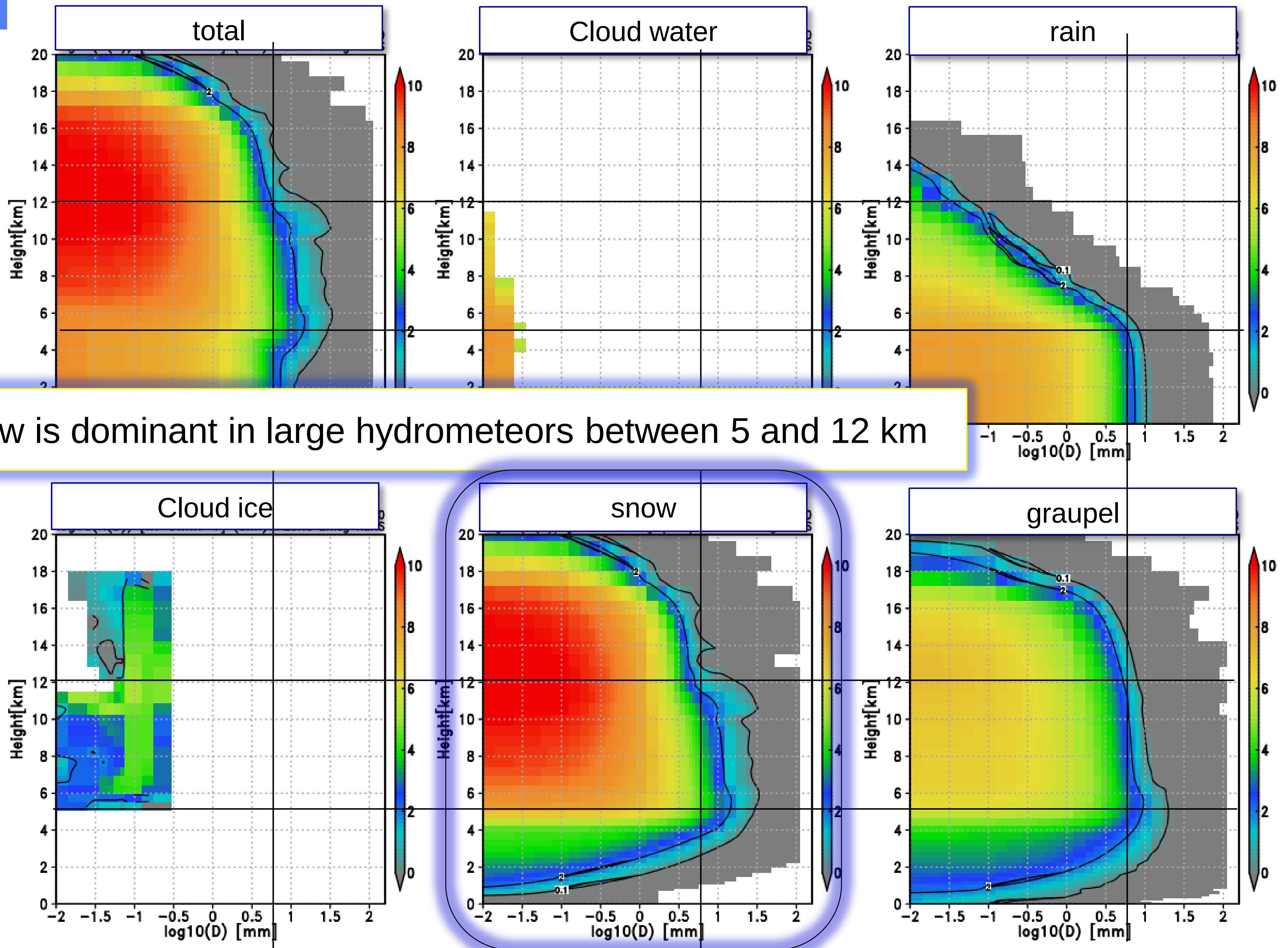
OB (retrievals)

FG



- DSD:
  - OB: gamma
  - FG: Inverse-exponential (rain,snow,graupel) and mono-disperse (cloud water,cloud ice)
- Large hydrometeors populations
  - OB: gradually reduces above 5 km
  - FG: nenarly stay constant below 12 km and reduces above 12 km

Number density of 5 hydrometeors in model as a function of diameter and height



Snow is dominant in large hydrometeors between 5 and 12 km

Assimilation scheme

- EnVA: Ensemble-based Variational scheme (Aonashi and Eito 2011)
  - Minimize a cost function in ensemble forecast error subspace (Lorenc 2003)

$$J(x) = J(\Omega) = \left(x - \overline{x^f}\right)^T \mathbf{P^{-f}}\left(x - \overline{x^f}\right) + (y - H(x))^T \mathbf{R^{-1}}(y - H(x))$$

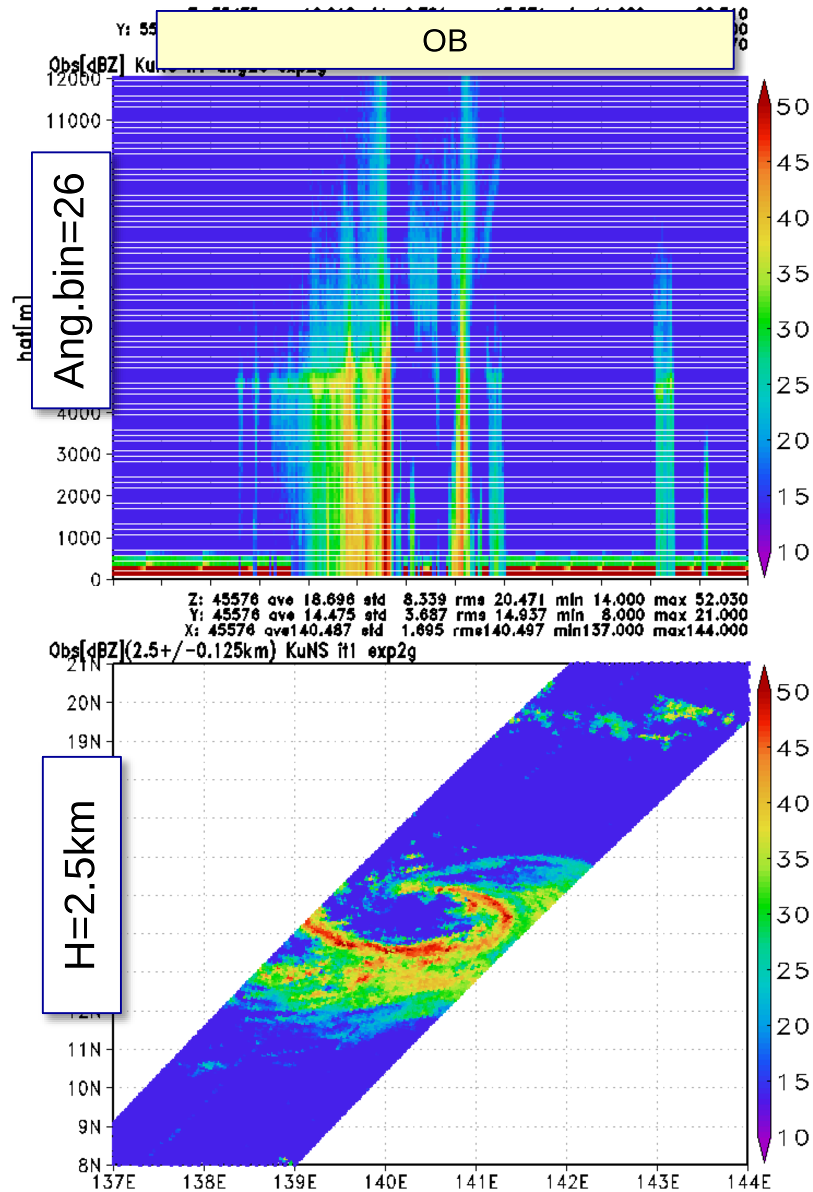
$$x - \overline{x^f} = P_e^{f/2} \circ \Omega \qquad P_e^{f/2} = \left(x_1^f - \overline{x^f}, x_2^f - \overline{x^f}, , , , x_N^f - \overline{x^f}\right)$$

$\mathbf{P^f} = \mathbf{P_e^f} \circ \mathbf{S}$: $\mathbf{S}$ spatial localization

- Improve EnVA to reduce sampling errors (Aonashi et al. 2016, submitted to MWR)
  - Neighboring Ensemble (NE) approach based on spectral localization (Buehner and Charron, 2007) in addition to an adaptive spatial localization
  - Dual scale analysis variables dependent on horizontal scale
    - Large-scale variables (x_L): U,V, Ps, potential temperature, RHW2 (=(Qw+Qi+Qc)/Qsat)
    - Small-scale variables (x_S): W, Pr (sum of flux of rain, snow and graupel) and anomaly from spatial averaged x_L

DPR pre-processings

- QC (Quality Control) removes data
  - At and above melting layer,
  - Contaminated by ground clutter,
  - Over land,
  - Having no rain signals in both OB and FG (Ze<14dBZ), or
  - Having large OB-FG
- Super-ob: average observation within two horizontal and vertical grids
  - GMI also averaged within 25x25 km
- Observation error = 4dBZ(KuNS), 3dBZ(KaHS)



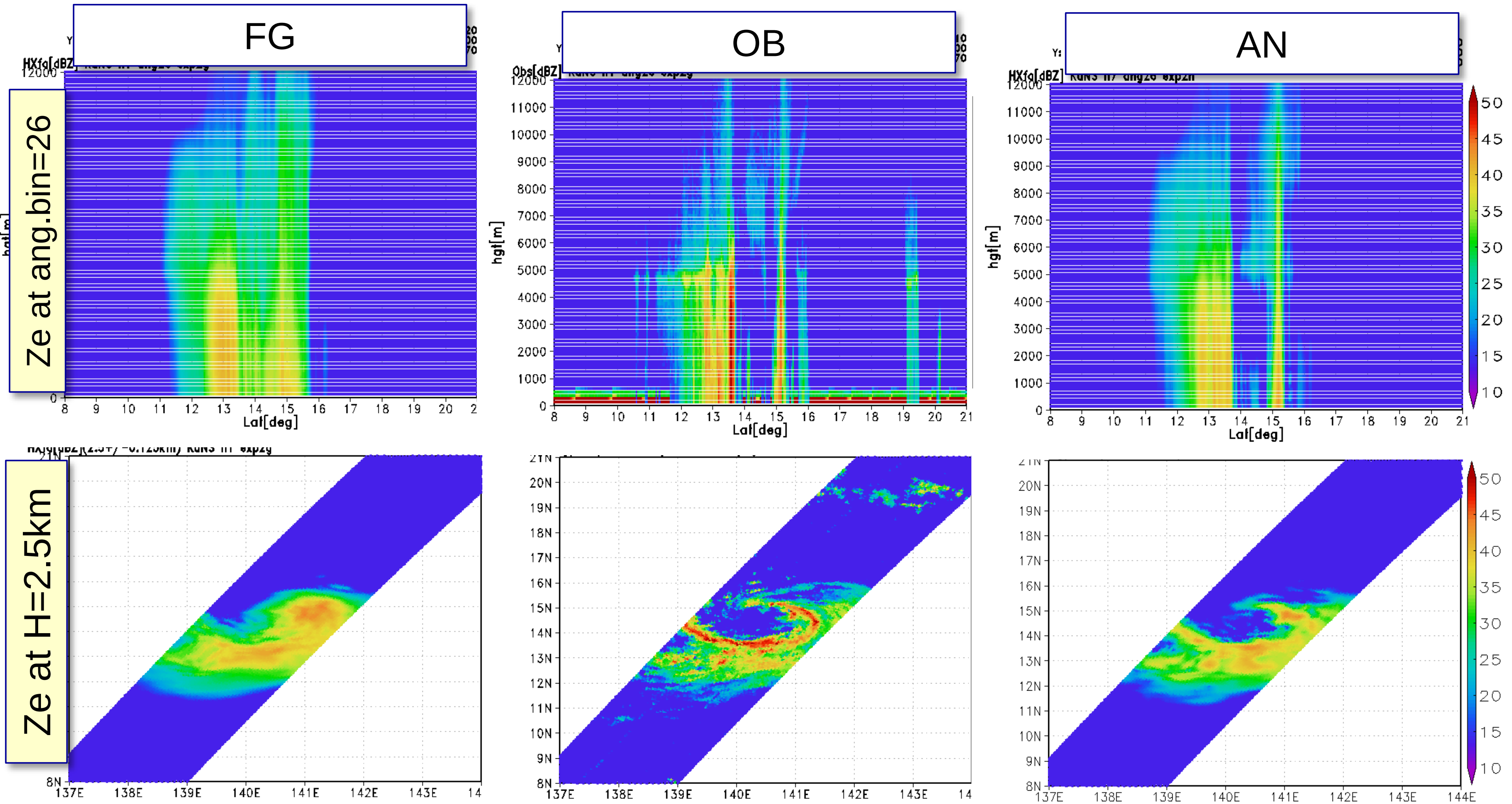
Assimilation experiments

Exp Name	GMI	KuPR (KuNS)	KaPR (KaHS)	conventional
1.Kuonly		O		O
2.Kaonly			O	O
3.GMIonly	O			O
4.GMI+Ku	O	O		O
5.GMI+Ka	O		O	O
6.GMI+KuKa	O	O	O	O

- Implement 6 non-cycle assimilation experiments
- Observation
  - 2ADPR (NS and HS) attenuation-corrected Ze
  - GMI radiance at 10V, 19V, 23V, 37V and 89V channels
  - Conventional data (bogus winds)
- Observation operator
  - Radar simulator : Joint-simulator (Hashino et al. 2013) for Ze
  - RTM: Liu (2004) for radiances
- Assimilation system
  - 5km, 401x401grids, 50-layer, 52 members

Example of assimilation result : Kuonly exp.

KuNS Ze cross section (H=2.5km & Angle.bin=26)



Analysis increment for 3 experiments (at 2.5km)

Kuonly

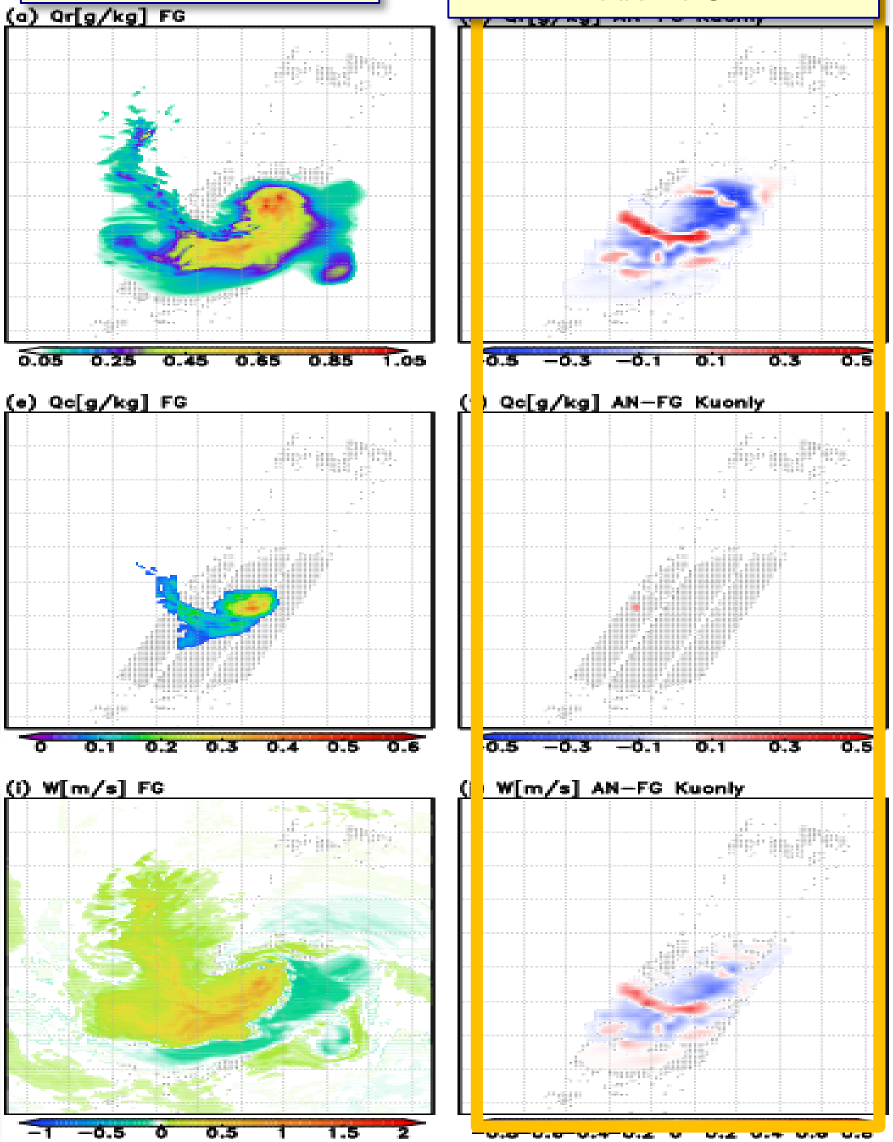
FG

AN – FG

rain [g/kg]

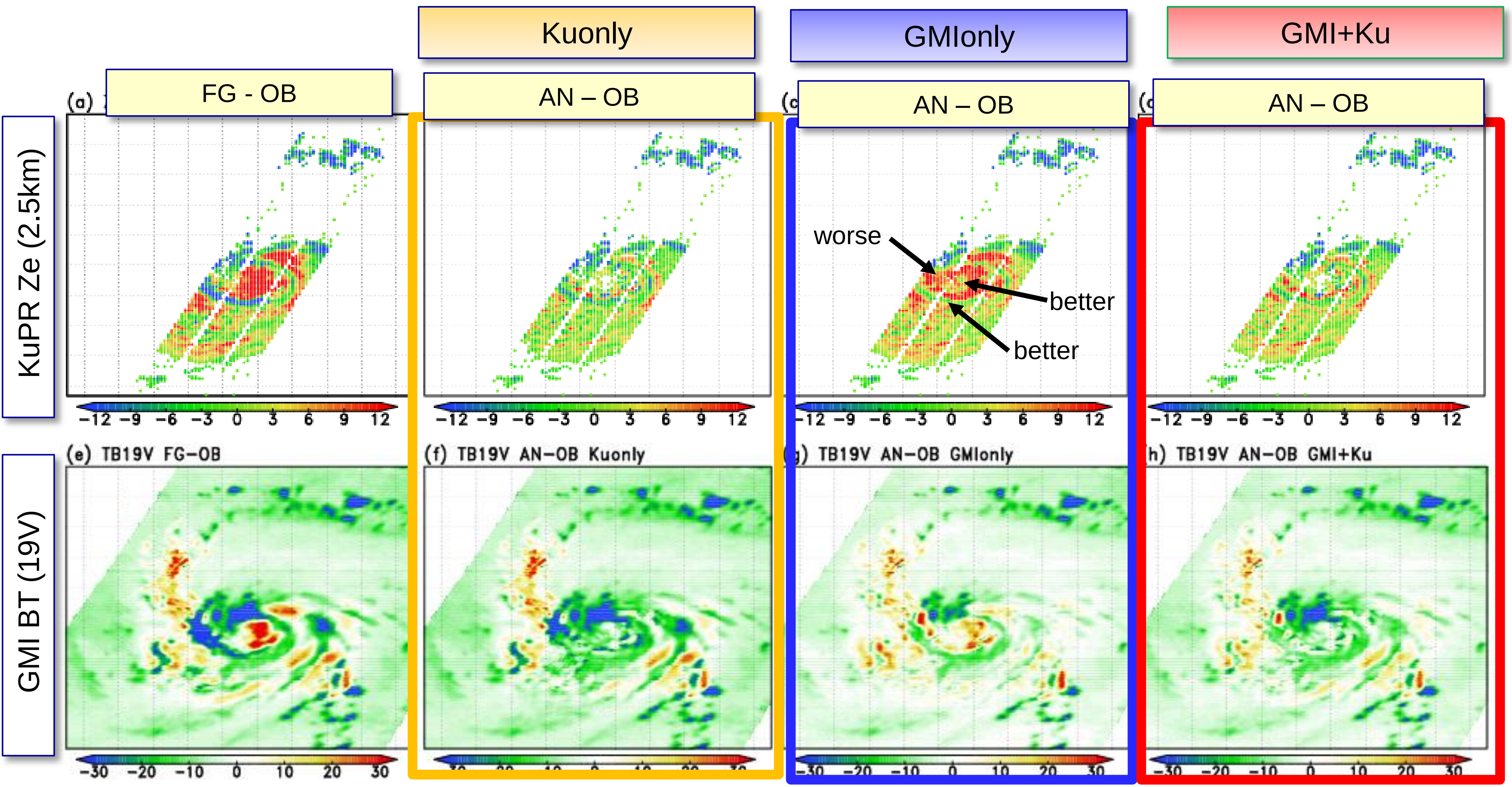
cloud [g/kg]

Vertical wind [m/s]

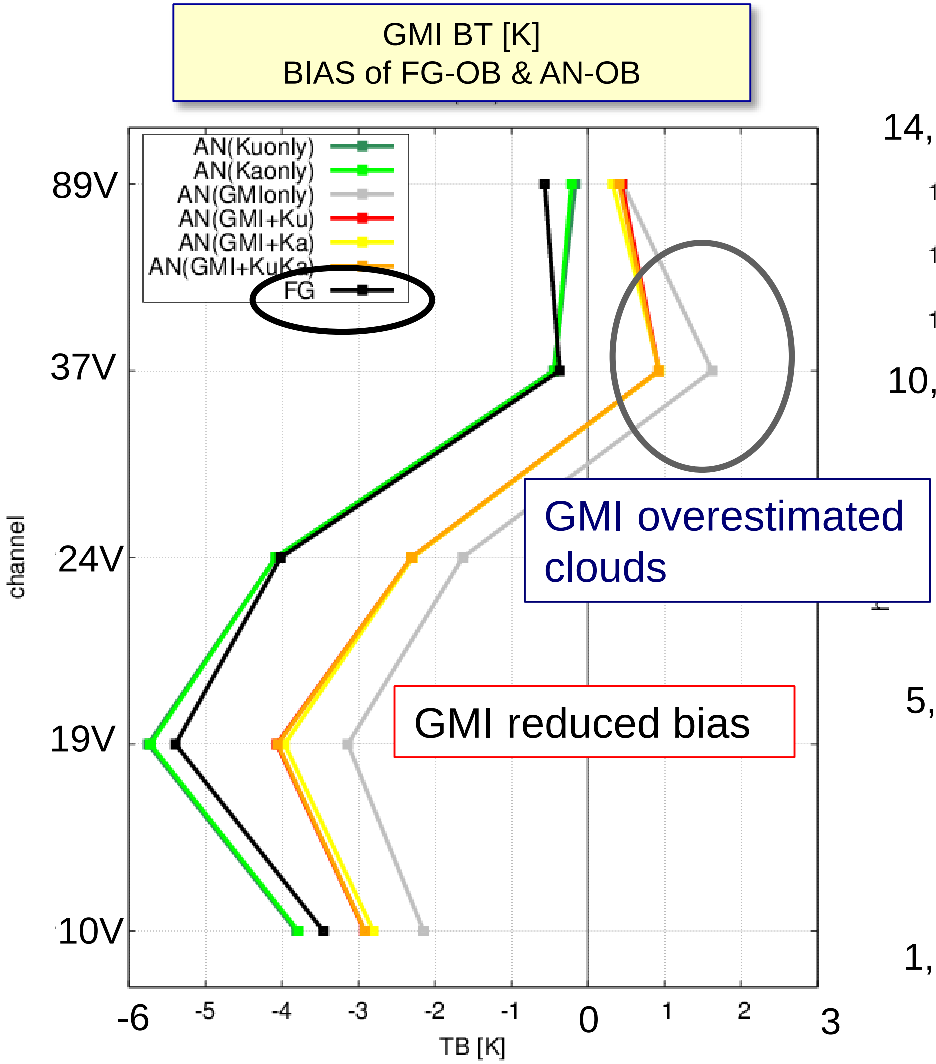


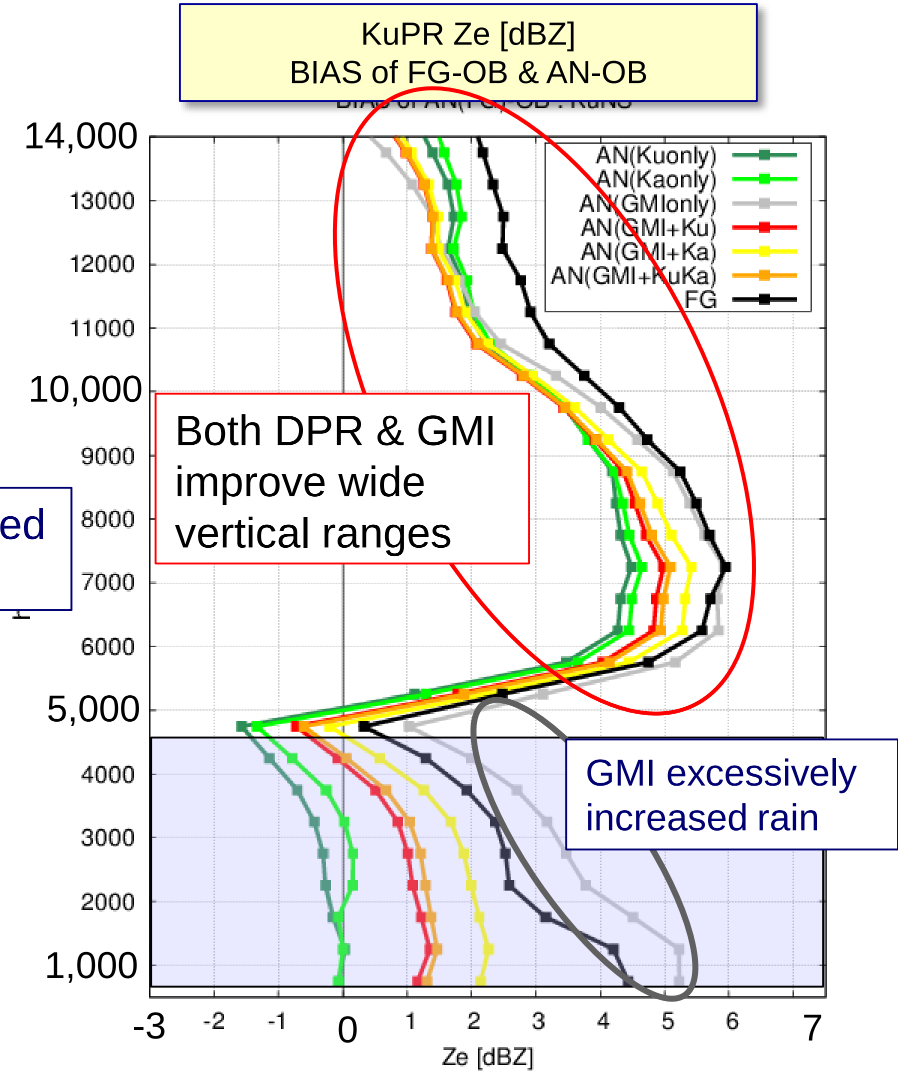
Analysis verification FG-OB & AN-OB

	GMI	KuPR	KaPR
1.Kuonly		O	
3.GMIonly	O		
4.GMI+Ku	O	O	



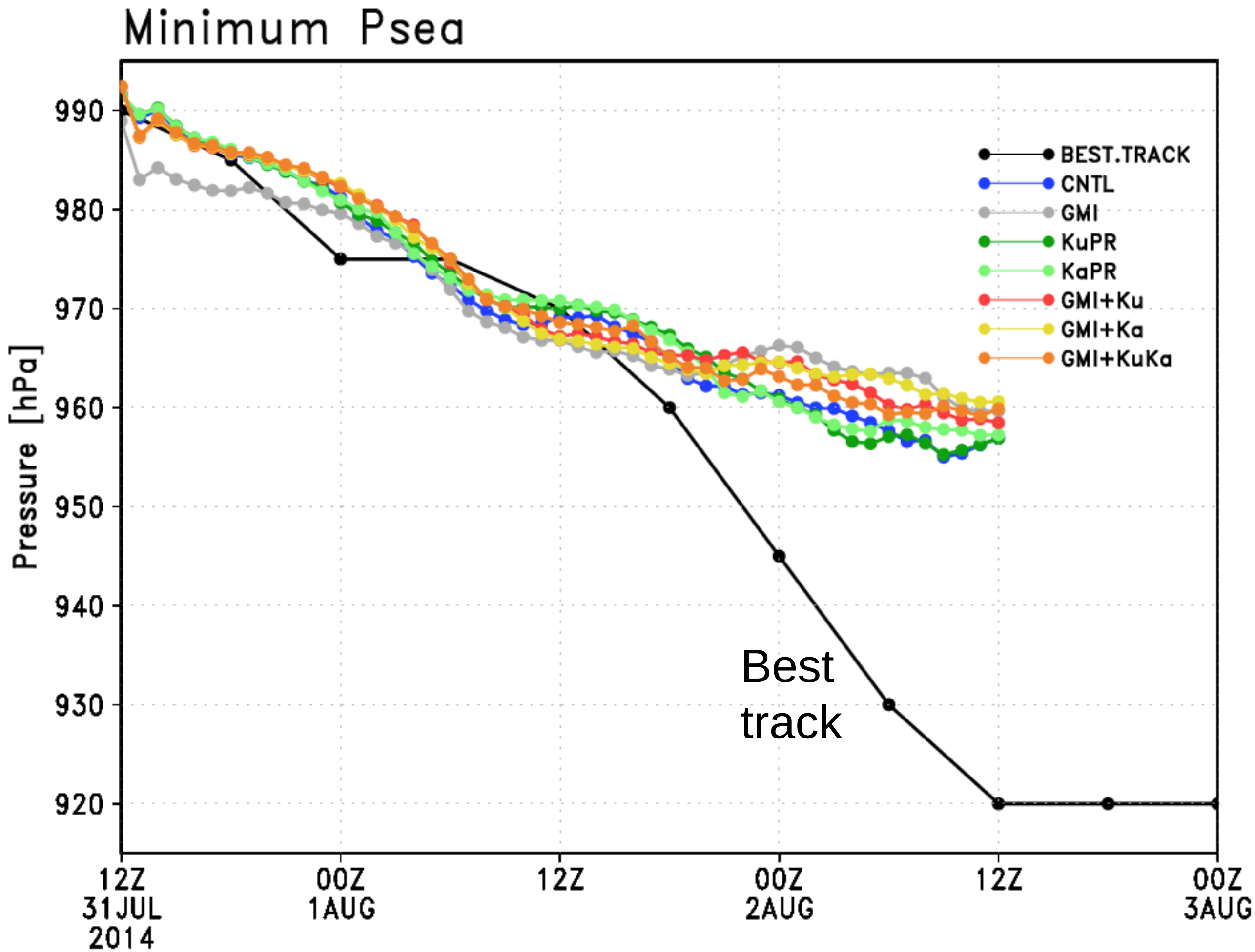
Analysis verification
Mean FG-OB & AN-OB





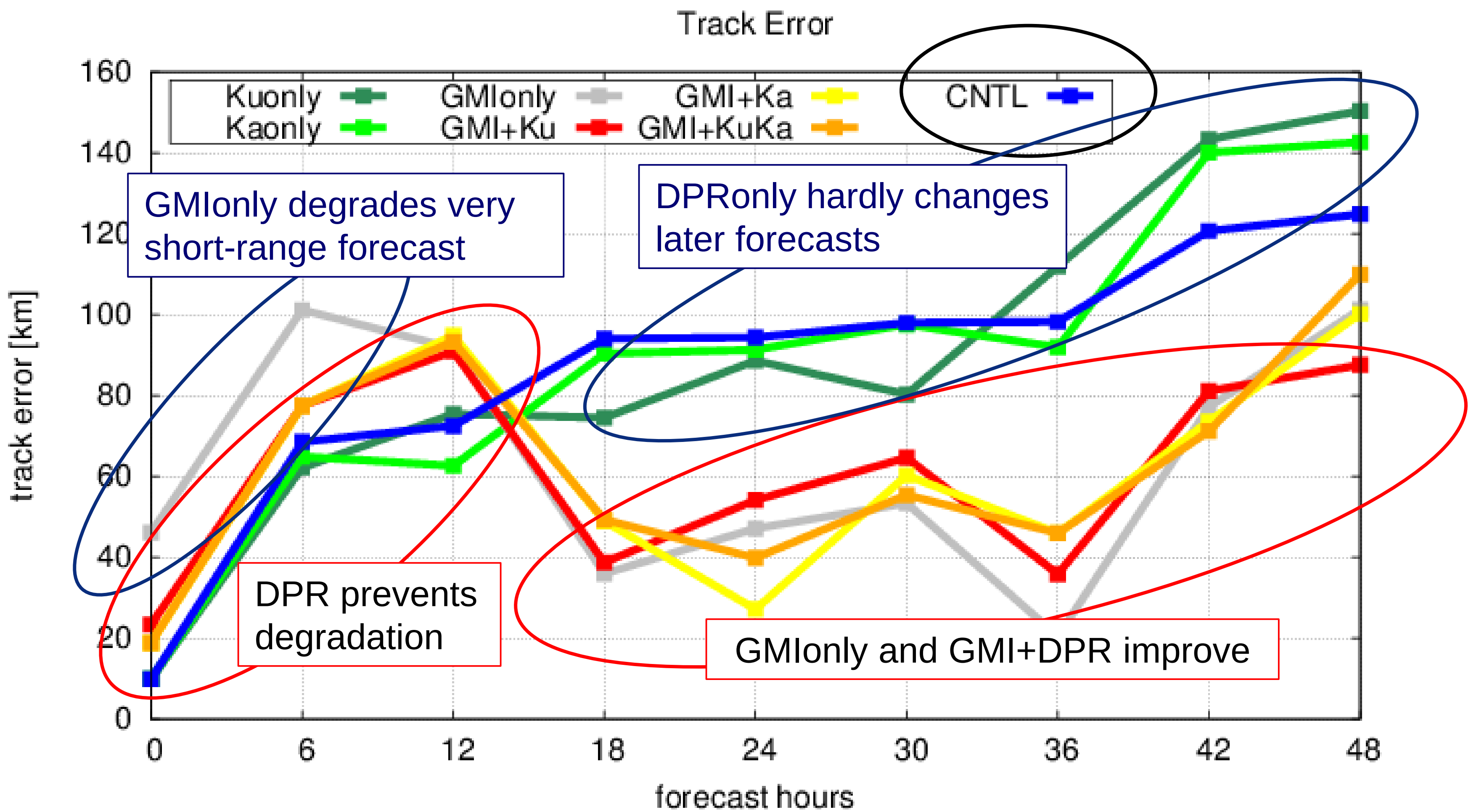
Forecast verification : intensity

- DPR (and GMI) assimilation cannot predict the rapid intensification of Halong



Forecast verification : Center positon

- DPR assimilation yields small errors in the very short-range forecast
- DPR + GMI reduces position errors over the entire forecast range



Summary of DPR reflectivity assimilation

- Comparison of GPM-core/DPR with model simulation
  - JMA-NHM overestimates Ze from snow
- Assimilate DPR Ze and evaluate analysis and forecast
  - Included Joint-simulator in an ensemble-based variational (EnVA) scheme and developed QC procedures for DPR Ze
  - Assimilating both DPR Ze and GMI radiances most improve analysis and typhoon track forecast
- <u>What we learned about DPR assimilation is</u>
  - Impact of DPR is limited due to narrow swath, sensitivity to restricted analysis variables and conservative QC (removing ice region)
  - Synergetic use with MWI and background covariance structure are important for effective use of DPR
- Plans
  - Cycle experiment, More cases
  - Improve use of KaPR by better handling ice scattering Ze (e.g. BC?)

Thank you for your attention!

- References

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